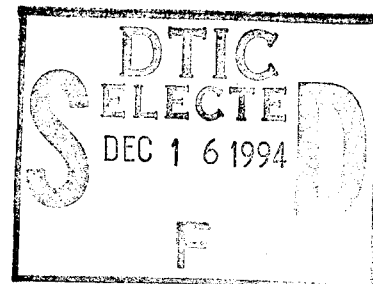


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Warfare Studies**



**The U.S.  
Commercial Space Launch Program  
and the  
Department of Defense Dilemma**

**William G. Clapp, Ed. D.**

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This memorandum recommends affordable and sensible actions for improving the US commercial space program in order to ensure US companies, as well as the Department of Defense, have continuing access to space using economical US rockets.

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THE US COMMERCIAL SPACE LAUNCH PROGRAM AND THE  
DEPARTMENT OF DEFENSE DILEMMA

As this study was prepared for printing, *Aviation Week & Space Technology* [15 August 1994] noted that the "Defense Department soon will depend heavily on the private sector for advanced space technology, as well as satellite communications, weather and multispectral surveillance support. . . ." The article noted that the military was still in the early throes of restructuring its space programs and that it was "driven largely by affordability issues and the proliferation of commercial space systems and services."

Dr. Clapp distills the dilemma facing the nation and military and makes sound policy recommendations for solving it. *Aviation Week & Space Technology* noted that military is rapidly reaching some of the same conclusions, namely, that the US must "develop interface standards that suit both commercial and military needs. Industry, military and government agency personnel must work together to develop a standard 'space architecture' that encompasses an efficient ground and on-orbit infrastructure."

This study will be of interest to anyone interested in the future of America's space programs.

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Captain, US Navy  
Assistant Director  
Strategic Research Department  
Center for Naval Warfare Studies

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NAVAL WAR COLLEGE  
Newport, R.I.

**THE US  
COMMERCIAL SPACE LAUNCH PROGRAM  
AND THE  
DEPARTMENT OF DEFENSE DILEMMA**

by  
William G. Clapp, Ed.D.  
Major, Utah Air National Guard

A longer version of this paper was submitted to the Faculty of the Naval War College in partial satisfaction of the requirements for an Advanced Research Program Elective.

The contents of this paper reflect the author's personal views and are not necessarily endorsed by the Naval War College or the Department of the Navy.

## Introduction

The US space launch program no longer dominates the world and is, in fact, playing "catch-up" with the world's first commercial launch company, Arianespace. A healthy US space launch program could provide considerable economic advantages and is essential to assure continued low-cost military access to space. Nevertheless, President Clinton's space policy prohibits development of new launch vehicles and limits the Department of Defense to upgrades of existing launch vehicles. Because the US commercial and military space launch programs are heavily interwoven, commercial programs have not been able to compete with Ariane due primarily to the rigidity of governmental regulations which prohibit them from making the rapid and innovative decisions required to be competitive. The effort to regain the lead in the commercial space launch market has also been hindered by declining Department of Defense budgets. Even though the US Government created the space sector, government programs should now be separated from commercial programs and allow them to compete internationally on equal footing. Until that happens, the Department of Defense should consider commercial space launch interests when making military decisions. Ariane provides the "bench mark" against which the US can base its progress. This paper identifies Ariane's advantages and makes low-cost recommendations for countering them. If they are enacted, the US can once again dominate the world commercial launch market and ensure affordable military access to space.

## Does the US have a commercial space launch problem?

The US space industry lost its lead in launching commercial satellites several years ago and is falling further behind every year. For 17 years, from 1965 to 1981, the United States launched every commercial satellite. This changed dramatically when the world's first commercial space launch company, Arianespace, went into business. Arianespace now dominates the commercial market by launching 65 percent of the world's commercial satellites. When China and Japan entered the field, the US market share was further reduced to less than 26 percent (Figure 1). An estimated \$1 billion each year is lost to outside space launch competition. The demise of the US commercial launch business will continue with the emergence of Russian commercial space launch programs and the debut of the Ariane 5 rocket. The future for US commercial space launch business looks grim unless immediate corrective action is taken.

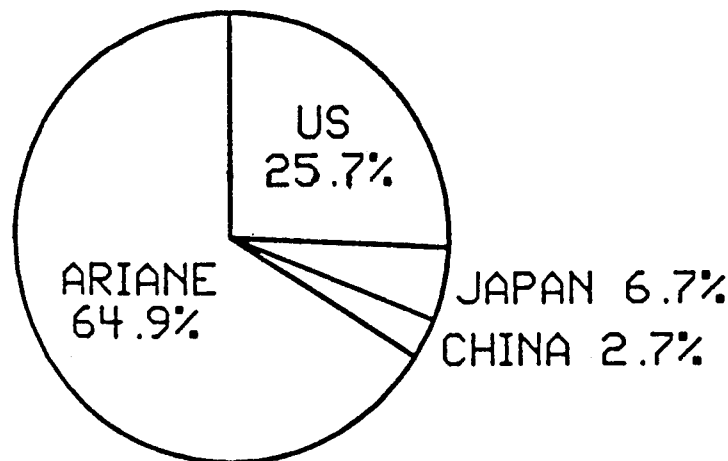


FIGURE 1. COMMERCIAL SATELLITE LAUNCH VEHICLES,  
1988-1992, 74 SATELLITES

## Why should Americans care about the US commercial launch program?

There are four reasons why Americans should be concerned about the future of US commercial space launch programs:

- *First, the economic well-being of the United States.* An estimated \$1 billion per year has been lost to foreign commercial space launch companies. World trade rules will be written by those who dominate the market and everyone else will have to play by them.<sup>1</sup>
- *Second, unnecessary expenditures of tax dollars.* Military space programs consume a large amount of tax dollars and every effort should be taken to keep those costs down. Competitive commercial space launch businesses that take on both commercial and military contracts can help keep military expenditures down.
- *Third, national pride.* President Kennedy was able to pull the nation together for the race to the moon because he believed that the United States could not be second in the eyes of the world, because second was last.<sup>2</sup>
- *Fourth, national security.* A healthy US commercial launch program will assure the military continued and affordable access to space. If, as I believe will be the case, space becomes the military high ground of the future, the American people should be very concerned about the future of the US commercial space launch program. Second will again be last.

## **What has the government done to help the commercial space launch program?**

Each of programs of the mainstay launch vehicle manufacturers (General Dynamics, McDonnell Douglas, and Martin Marietta) are products of the 1960's government-sponsored space race. As a result, commercial launch programs have had a difficult time extricating themselves from the government space program. Government, military, and commercial launch programs remain interwoven in a patchwork quilt of restrictive, overlapping, inconsistent, and politically-driven US space policies.

Despite the plethora of government surveys, studies and committees assessing the space program, the problem remains and recommendations to Congress have either been ineffective or ignored. During the Bush Administration, *The Vice President's Space Advisory Board Report*, November 1992, and the *Final Report to the President on the US Space Program*, January 1993, both recommended development a new family of launch vehicles and centralized management of the space program. These recommendations became infeasible when, as a result of a declining economy and the end of the Cold War, military budgets became easy prey for the budgeteers.<sup>3</sup> President Clinton has once again studied the problem hoping a less expensive plan of action could be found.<sup>4</sup> A recently released draft of Clinton's launch policy recommends that the military be limited to making incremental improvements to the existing Atlas, Delta, and Titan launch vehicles.<sup>5</sup> This will have a negative impact on both the military and commercial space launch programs.



### **Does the government need to rescue US commercial launch companies?**

US commercial space launch programs don't need rescuing, they need to be freed from burdensome policies that prohibit them from making competitive decisions. For example, Martin Marietta's commercial division was able to launch just three satellites before the government decided to convert a Titan 3 to a Titan 4 launch pad. That decision left only one East Coast Titan 3 launch pad capable of launching commercial satellites. A second launch pad on the West Coast is not usable because it is not capable of launching commercial satellites into geostationary orbit. The launch pad was out of commission for two years forcing customers to seek launches elsewhere. By permitting US commercial space launch programs to operate independently of government programs, they will be able to make long-range decisions which have heretofore been taken out of their hands as well as being able to take advantage of rapid changes in technology.

### **Why was Ariane able to capture the commercial launch market?**

Arianespace recognized the potential of space transport market and built a line of launch vehicles tailored specifically to the needs of the world's commercial satellite organizations.<sup>6</sup> Ariane's competitive advantage comes from the following sources:

- *The Ariane family of space launch vehicles was specifically designed to meet commercial requirements, which for the most part involve putting*

communications and observation satellites into geostationary orbit.

Ariane is able to deliver payloads directly to geostationary transfer orbit.

- *Ariane offers 16 different launch configurations covering a broad range of payload sizes at consistently low prices.*
- *Ariane also offers a multiple payload launch capability that allows various sized satellites to be matched to one of the 16 launch configurations.*

This flexibility allows Ariane to achieve a consistently high maximum payload.

- *The Kourou (French Guiana) launch facility, located near the equator, provides a 15% energy savings over US launched spacecraft bound for geostationary orbit.<sup>7</sup>*

These four advantages are enough to explain why Arianespace was able to capture the commercial launch market.

### **What about other foreign launch competition?**

China, Japan, and Russia have launch vehicles capable of competing with the United States and Ariane. Launch competition from these three countries has been temporarily held at bay because of satellite export restrictions imposed by the United States. Since 69 percent of the world's commercial communications satellites scheduled for delivery from 1992 to 1997 will be built by a US prime contractor,<sup>8</sup> the US government can place satellite export bans on them in order to protect the US commercial launch business. A number of reasons

have been used to justify these bans. Export licenses have been withdrawn from China for price dumping, human rights violations and disregard of international missile proliferation.<sup>9</sup> In 1989 the Russians were denied export licenses for illegally transferring technology and for price dumping. President Bush reversed the decision in 1992 and approved one launch of a US built satellite in Russia.<sup>10</sup> A more recent US and Russian agreement was reached in 1993 allowing eight Russian Proton launches of US geostationary commercial satellites through the year 2000.<sup>11</sup> Both the Chinese and Russians have obtained commercial contracts for launching non-US built satellites. Concerns such as these prompted the US government in 1988 to limit the number of international satellites launched (to nine) between 1988 and 1994.<sup>12</sup> Foreign competition is rapidly growing and this strategy will ultimately prove ineffective, if not damaging.

The Japanese, on the other hand, have not offered competitive prices to foreign commercial satellite customers. The earlier N1 and H1 launch vehicles (hybrid American and Japanese designs) were never competitive even though they were very reliable. The new Japanese H2 is one of the world's most efficient heavy launch vehicles, but the high development costs have temporarily prohibited competitive launch pricing.<sup>13</sup> The Japanese intend to reduce the costs of their H2 to make them competitive with the Ariane by simplifying production with increased automation and reducing material costs by using cheaper materials and simpler structures.<sup>14</sup> Another tremendous setback for

the Japanese H2 has been the political and environmental restriction of only being able to make four launches per year due to concerns of the local fishing industry.<sup>15</sup> The Japanese will become a competitive launcher of commercial satellites when they: (1) reduce costs, (2) increase the number of flights per year, and (3) establish a history of success.

### **How will the US compete with the emerging foreign launch competition?**

For nearly a decade, Ariane has consistently launched more commercial satellites than all of the US launch vehicles combined. The US is finding that playing "catch-up" is considerably more difficult than keeping up with foreign launch competition. Lester Thurow, author of *Head to Head*, provides the steps required to catch up with the competition.

A country that wants to win starts by closely studying the competition. The purpose is not emulation but what the business world calls "bench marking." Find those in the world that are best at each aspect of economic performance. Measure your performance against theirs. Understand why they are better. Set yourself the target of first equaling, and then surpassing, their performance.<sup>16</sup>

Arianespace was selected as the "bench mark" for this study because they are currently the commercial leader in space launches. Four areas have been selected for further analysis that will help identify an American strategy for regaining the commercial space market, namely launch vehicle: (1) payload characteristics, (2) delivery costs, (3) selection process, and (4) technology. Program comparisons uncovered a number of differences that gave Ariane a significant advantage and also offered recommended strategies for "catching-up"

and "getting ahead."

*Payload Characteristics.* Payload characteristics were selected as the first performance standard because the sole purpose of a launch vehicle is to deliver its payload to a particular stellar location. Between 1965 and 1992, 392 communications and observation satellites were placed into geostationary orbit. Just over 50 percent (198) of these were commercial satellites. Even though Ariane has only launched 66 satellites compared to the US's 117 (Figure 2), it

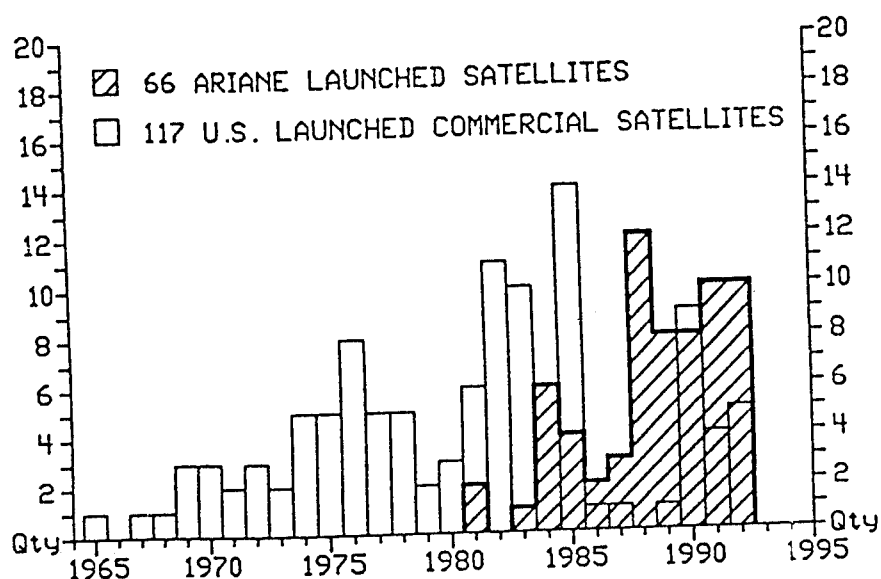


FIGURE 2. ARIANE VS. US LAUNCHED COMMERCIAL SATELLITES must be remembered that Ariane came late to the game. Arianespace's goal has never been to monopolize the market but to launch half of the world's commercial satellites.<sup>17</sup> Their goal will become a reality within the next few years.

An average of fifteen commercial satellites per year are being launched and that number is predicted to steadily increase.<sup>18</sup> Average payload weights have also steadily increased (Figure 3) from the first 39 kg (86 lb) Intelsat 1 to an average of nearly 1200 kg (2700 lb).<sup>19</sup> Commercial satellite quantities and

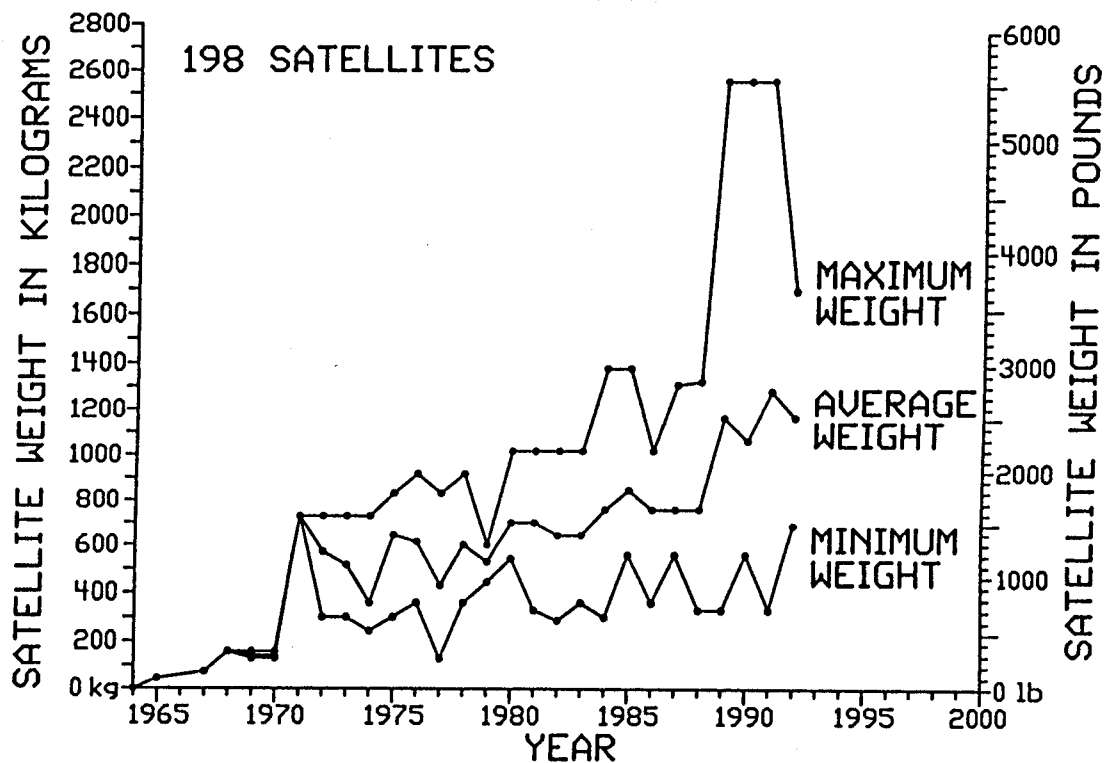


FIGURE 3. COMMERCIAL SATELLITE WEIGHT, 1965-1992

size will continue to increase in the foreseeable future. Ariane closely monitors increasing payload sizes and ensures that their vehicle upgrades keep up with commercial needs. US launch vehicles, on the other hand, are still being tailor made to specific military payloads.

*Delivery Costs.* Commercial satellites typically are designed to go to geostationary orbits where they travel in synchronization with the Earth's rotation and, thus, do not move relative to a position over the ground. Space launch vehicles generally do not take payloads directly to geostationary orbit but rather to a geostationary transfer orbit (GTO) where payload boosters take over. A GTO is a highly elliptical orbit used to take the payload out to 22,300 miles where the satellite booster motor fires to move the satellite into its final circular geostationary orbit (GEO). For this study, launch costs were estimated using payload costs per pound to reach a geostationary transfer orbit. To do this, overall flight costs were divided by payload weight to obtain the

cost per pound rate. US Atlas, Delta, and Titan launch costs were compared to "bench marked" Ariane launchers for all commercial flights between 1988 and 1992.

Atlas 1/2, Delta 2, and the Titan 3 cost per pound rates were found to be significantly less than Ariane 4 — by as much as 25% (Figure 4). The lowest rates were commonly achieved by US launch vehicles carrying military satellites.

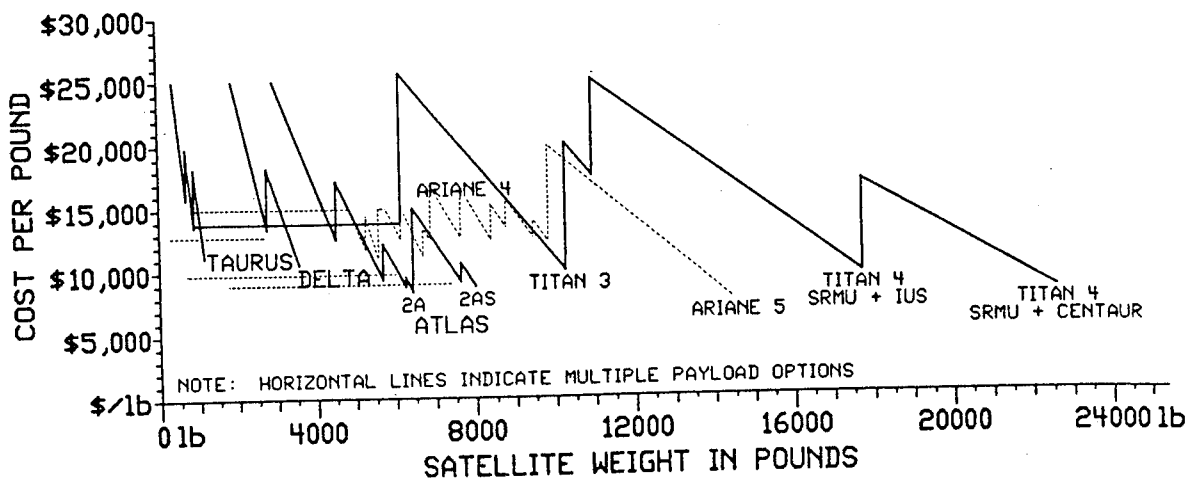


FIGURE 4. ARIANE VS. US LAUNCH VEHICLE COSTS

The reason is simple — military satellites typically used 100 percent of the payload capacity of tailor-made US launch vehicles.<sup>20</sup> Accusations continue to be made that US launch vehicles are too costly because, unfortunately, commercial satellites have been poor matches for US launch vehicles and have averaged less than 80 percent of the rated payload capacity.<sup>21</sup> Ariane payloads, on the other hand, averaged more than 90 percent of the rated maximum payload.<sup>22</sup> Therefore, the average launch costs for commercial satellites aboard US launch vehicles was slightly greater than \$17,500 per pound, whereas, Ariane dual-payload launch costs averaged \$15,600 per pound and single-payload launches

averaged only \$12,200 per pound.<sup>23</sup>

Ariane's lower average rates are attributed to their multiple payload capability and numerous launch configurations. Different size payloads are matched to maximize weight capacity using one of Ariane's 16 different launch configurations. US launch vehicles, on the other hand, are limited to single payload launches using only a few different launch configurations.

Another Ariane advantage is their launch site in Kourou. It offers significant energy savings over US launches because it is nearer the equator. A 15 percent heavier payload could be carried on US space vehicles launched from a site near the equator. Thus launched from the same site, rates as low as \$7,500 per pound for Atlas 2A, \$9,300 per pound for Delta II 7925, and \$8,800 per pound for Titan 3 could be realized, compared to Ariane's average of \$12,000 per pound.

*Selection Process.* Launch vehicle selections were reviewed for all commercial launches between 1988 and 1992 to identify basic criteria used by satellite owners. As expected, launch vehicle decisions were found to be primarily dependent on cost per pound rates. A number of basic pass/fail criteria were first analyzed before concluding cost was the predominant criterion. Also considered were reliability, warranty, accuracy of placement, stress on the payload, export restrictions, and launcher availability. A few exceptions to the lowest cost selection criteria were noted — some organizations and countries, for example, had loyalties to particular manufacturers. China, France, Russia, and the US military have always used specific launch vehicle manufacturers within their own countries. Even a few international satellite communications companies with worldwide ownership seemed to have launch vehicle manufacturer preferences that related to the ownership percentages.



But, without a doubt, most launch vehicle selection decisions were based on cost per pound rates to deliver payloads to geostationary transfer orbit.

*Technology.* The review of launch vehicle technology was divided into three areas: (1) engine efficiency, (2) payload-to-takeoff weight ratios, and (3) success rates. Engine efficiency was measured using specific impulse (Isp), which is a ratio of the amount of fuel consumed to maintain a particular engine thrust. The payload-to-takeoff weight ratio compares the satellite weight to the rocket mass expended to deliver the payload to a geostationary transfer orbit. Reliability was determined by past performance in getting a payload to reach the desired orbit.

Liquid-engine performance ratings have not changed significantly in the last 30 years and all of the world's launch vehicle manufacturers use the latest liquid-engine technology. The Russian Proton engine, developed in the 1960s, remains the most efficient kerosene liquid-engine in use and the Shuttle liquid hydrogen and oxygen main engine, developed in the 1970s, is the world's most efficient rocket engine.<sup>24</sup> Unlike liquid-engines, solid propellant motor performance has been slowly improving. The Titan 4, SRMU solid propellant strap-on booster, is the world's most efficient. Ariane launch vehicles use conservatively rated engines and are less efficient than any of the US engines. Despite these facts, there seems to be little advantage in the type of engine used for launch vehicles because the cost-to-performance tradeoffs are not significantly different (i.e., the more expensive higher performance liquid-engines do not offer cost advantages over the cheaper lower performance solid booster motors).

Payload-to-takeoff weight performance ratios were found to be a relative indicator of payload launch costs. Most geostationary transfer orbit launch

[illegible]

Generally, launch vehicles offering the lowest cost per pound rates also have higher payload-to-takeoff weight ratios. The Atlas has the highest payload-to-takeoff weight ratio, 1.6%, of all the world's launch vehicles.<sup>25</sup> The Titan 4 with the SRMU solid strap-on boosters and the Centaur upper stage has a higher ratio than all of the Ariane configurations while the Delta is in the lower third, below Ariane.

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There were a number of reasons for this phenomenon: (1) a rescheduled flight on another launch vehicle would have delayed the launch for about two years, (2) contract penalties would have been costly, and (3) there was a high probability that the launch vehicle problem would be corrected before the next flight. Customers that unfortunately lost their payload to a launch vehicle failure typically recouped a percentage of satellite construction costs from flight insurance and were offered a free replacement launch as part of the warranty.

#### **Recommendations to regain US commercial launch dominance.**

Arianespace recognized the potential of commercial space transportation and built a line of launch vehicles tailored specifically to the needs of the world's commercial satellite owners.<sup>26</sup> To quickly review its strategy: (1) because commercial payloads are typically communications and observation satellites which require a geostationary orbit, Ariane designed its family of space launch vehicles to deliver payloads directly to geostationary transfer orbit; (2) it opted to offer numerous configurations covering a broad range of payload sizes which could be launched at consistently low prices; (3) it also designed its vehicles with a multiple payload launch capability, allowing different sizes of satellites to be matched to one of the configurations in order to achieve a consistently high maximum payload; finally, (4) it selected a launch site located near the equator providing a 15 percent energy savings over US launched spacecraft.<sup>27</sup> It was a brilliant strategy and it worked. Arianespace captured the commercial launch market.

Nevertheless, the data shows that when Ariane launch vehicles are compared to equal size US launch vehicles, US launch vehicles can be more economical in most cases. However, US launch vehicles lack multiple launch

capability and are capable of offering the lowest rates for only one size of satellite (the one that fits their maximum vehicle weight capacity). The analysis shows that by following a number of recommendations, the US could "catch-up" and "get ahead." Several of these recommendations involve funding outlays by the Department of Defense even though the primary beneficiary appears to be the commercial space sector. While this may be true in part, ensuring that the military has affordable access to space is essential for guaranteeing America's security interests. The recommendations also fit neatly within the Clinton Administration preferred "dual purpose" strategy whereby government spending benefits both the public and private sector. The recommended investments are relatively low cost but promise a high pay off.

### **Recommendations**

*Recommendation 1.* The Department of Defense should fund a multiple payload option upgrade for existing Atlas configurations in order to compete with Ariane 4 multiple launch capability. It should also fund a multiple payload option (i.e., four or more satellites) to upgrade the existing Titan 4, SRMU and Centaur configuration, in order to compete with the Ariane 5 multiple launch capability.

The most important difference between Ariane and US launch vehicles is Ariane's ability to launch multiple payloads. This one advantage is the key to understanding why Ariane now dominates the commercial launch market. US launch vehicles have full load rates as low as \$7,500 per pound for the Atlas 2A, \$9,300 per pound for the Delta II 7925, and \$8,800 per pound for Titan 3, but their average cost for commercial satellites has been an incredibly high \$17,500 per pound. Most launch vehicles flew with half empty cargo holds because they

were not able to match payloads to optimize the payload capacities.

The military Titan 3 has the same payload capacity as the Ariane 4 and has been launching dual payloads for the military for over 20 years. However, Titan 3 upgrades did not keep up with increasing commercial payload sizes and therefore were not competitive. The Titan 3 was also designed to be both a low-Earth and a GTO launch vehicle with design efficiency emphasis on low-Earth orbit injection. Because of the low-Earth design emphasis, the second stage must go to low-Earth orbit before sending the last stage on to a geostationary transfer orbit. This arrangement makes the Titan 3 less efficient at sending payloads to geostationary orbit. The Atlas, on the other hand, is a perfect candidate for a multiple payload configuration upgrade. The Atlas is smaller than the Ariane 4, but could lure many smaller payloads from Ariane. Ariane would then have a difficult time matching the larger payloads for multiple payload Ariane 4 and 5 configurations. Going after the smaller payloads is one way to regain part of the commercial launch market.

The Ariane 5 multiple launch configuration will be capable of launching three satellites. This will provide a tremendous opportunity for Arianespace to match an even wider range of payloads to fill the spacecraft to its takeoff limit. Costs will be unbeatable unless the US matches it with a Titan 4 SRMU and Centaur configuration capable of launching four or more satellites to a geostationary transfer orbit. The Titan 4 also needs to be modified for a more efficient flight trajectory that would go directly to a geostationary transfer orbit instead of stopping at low-Earth orbit.

*Recommendation 2.* Fund economical launch vehicle upgrades which increase the number of launch configurations available, thus widening the payload window while keeping cost per pound rates low. The second most

significant technical advantage Ariane has is their ability to accommodate a wide variation of payload weights by using 16 different launch configurations. US launch companies have been forced to phase out older configurations when they were no longer needed for military payloads. Every effort should be made to increase the number of usable launch configurations for Atlas, Delta, and Titan launch vehicles.

*Recommendation 3.* The Department of Defense and commercial launch companies should build a launch facility near the equator in order to match Ariane's 15 percent savings in geostationary launch costs. A new US launch facility would provide immediate cost savings for all flights to geostationary orbit. Ariane is not the only organization that will be taking advantage of equatorial launches, representatives from the Space Transportation Systems, Ltd., of Australia, and four Russian enterprises have signed an exclusive 20 year, \$750 million contract, for commercial equatorial launch services from Papua, New Guinea. The Russians claim the Proton can lift an additional 40 percent payload from the equator over their own northern Baikonur Cosmodrome launch facility.<sup>28</sup> The US already owns two islands near the equator that could be used for a new US launch facility. Baker and Howland Islands, south of the Hawaiian Islands, are located closer to the equator than either New Guinea or Kourou. The initial investment would take many years to recover but the advantages may make the difference for US space launch survival. A cost saving launch facility near the equator makes sense when one considers that geostationary satellites will be needed for decades to come.

*Recommendation 4.* Reduce the size and weight of future military satellites to conform with the size and weight of commercial satellites. This would benefit both the US military and commercial launch sectors by providing

common designs. Military payloads have traditionally been designed with little concern for size and weight, which means that military payloads have seldom been the same size and weight as commercial payloads. The Titan 3 was designed over 30 years ago, and is capable of carrying military payloads that are many times larger than most commercial payloads. The Titan 4 is also a very heavy lifter and is capable of carrying more than twice the weight of today's largest commercial payloads. By scaling back military satellites, common spacecraft can be used for launching both military and commercial payloads.

*Recommendation 5.* Continue and encourage the separation of military and civilian space launch programs in order to provide the commercial sector enough freedom to make competitive choices and react quickly enough to catch commercial opportunities. Add a civilian contingent to both the US Space Command management structure and the Pentagon with authority to influence military decisions that concern commercial launch issues.

### **Closing Remarks**

The survival of US commercial launch programs is, to a large extent, in the hands of the Department of Defense until commercial programs can become autonomous. Ground operations, launch facilities, and space policies are largely government controlled, even though each of the three major launch companies (General Dynamics, McDonnell Douglas, and Martin Marietta) have their own commercial divisions and manufacture their own spacecraft. Too many military decisions are being made that negatively impact the future of the US commercial launch business. Until commercial launch companies can break away from military entanglements, they will be unable to make the decisions required to secure a future in the world's commercial launch market. On the

other hand, selective Department of Defense funding of launch upgrades and a new launch site could establish a secure future for the US commercial launch program.

In conclusion, unless something is done quickly to improve US launch capabilities, it will never "catch-up" with Arianespace. The US government created the space sector and should do what it can to regain world dominance. Ariane, which is beginning to exercise significant influence on international trade rules, will fight any subsidized launch vehicles. This means US government and commercial sector ties must be severed. However, the Department of Defense must consider commercial space launch interests when making decisions. Ariane provides an excellent "bench mark" for the US to base future launch vehicle upgrades. If the US sets the target of first equalling, and then surpassing, Ariane by incorporating these recommendations, the US could once again dominate the world commercial launch market.



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17. Arianespace, *op. cit.* in note 6, p. 6.

18. Clapp, William G. "Geostationary Launch Vehicles and the U.S. Dilemma." Unpublished Research Paper, U.S. Naval War College, Newport, RI: 1994, p. 2-4.
19. *Ibid.*, p. 2-12.
20. *Ibid.*, p. 3-20.
21. *Ibid.*, pp. 3-15, 3-21, and 3-34.
22. *Ibid.*, p. 3-9.
23. *Ibid.*, Calculated from information from Appendices C, E, J.
24. *Ibid.*, p. 5-2.
25. *Ibid.*, p. 5-6.
26. Arianespace, *op. cit.* in note 6, p. 5.
27. *Ibid.*, p. 11.
28. Mecham, Michael. "Proton Group Signs Papua Services Pact." *Aviation Week & Space Technology*, September 20, 1993, p. 91.